Westport

Natural Gas Engine Technologies – Pathway for Hydrogen in Heavy-Duty Vehicles

Cummins Westport Inc.

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Cummins Westport Inc.

- Cummins Inc. and Westport Innovations Inc. signed a 50/50 Joint Venture Agreement in March 2001 and formed CWI
- CWI develops, supports and markets low-emission, high-performance gaseous-fueled engines.
- CWI leverages Cummins worldwide distributor network for Sales and Services
- Cummins Inc and Westport continue to provide technology development support for their Joint Venture

Our Belief

- Clean, efficient internal combustion engines will continue to dominate the transportation and industrial markets for many decades
- Energy policies and emissions concerns will continue to make natural gas an attractive commercial vehicle fuel globally
- As emissions challenges continue to become more difficult, NGV will become increasingly cost-effective

Overview

- Summary of Achievements With NG Engines
- Where we are Going with NG
- NGVs as Pathway to Hydrogen
  - Hydrogen in Heavy-Duty Vehicles
  - HCNG/Hythane
  - Pure Hydrogen Engines
- Summary

Summary of Achievements

Technology leadership with gaseous fuels:

1988: 1st to develop and demonstrated Lean Burn concept
1992: First CARB certification at 2 g/bhp-hr (standards at 6 g/bhp-hr)
1994: Early work on HCNG
1995: First full electronic closed loop HD NG engine
1997: First ULEV certification
2001: C Gas Plus introduction at 1.5 g/bhp-hr
2001: First demonstration of HD Trucks using NG DI (Norcal Waste)
2003: Development of HCNG calibration

We acknowledge DOE support for technology development

Summary of Achievements

Market leadership with gaseous fuels

- Introduced 4 Engine Families (150 to 300 hp)
  - B Gas Plus - B LPG Plus
  - C Gas Plus - L10G
- CWI engines integrated in over 30 vehicle chassis
- Cummins/CWI sales: approximately 9,000 engines since1990
- Presence in over 10 countries
- Over 7000 NG buses (all OEMs) in the US in 2002! That's nearly 15% of the current fleet. About ½ are Cummins/CWI

Cummins Westport Powers Beijing Public Transit

- 1800 B5.9G engines since 1999
- 18 hr per day, 7 days per week
- Largest B5.9G bus fleet in the world
- 10,000 diesel buses to be replaced by 2008 Olympics
- Currently discussing potential to introduce hythane buses

Where are we Going with NG?

Continuing Technology Leadership:

- Development of SI-EGR-TWC engine for 2010 emissions w/o SCR or LNA!
- Development of DI-EGR-DOC for sub-2007 emissions
- Pursuing work on hydrogen-natural gas mixtures

Plans for new products:

- 2004: L Gas Plus – rating up to 320 hp, targeting refuse haulers
- 2004: ISXG – rating up to 450 hp, targeting Class 8 trucks

NGVs as Pathway to Hydrogen

Hydrogen in Engines – Our Motivation

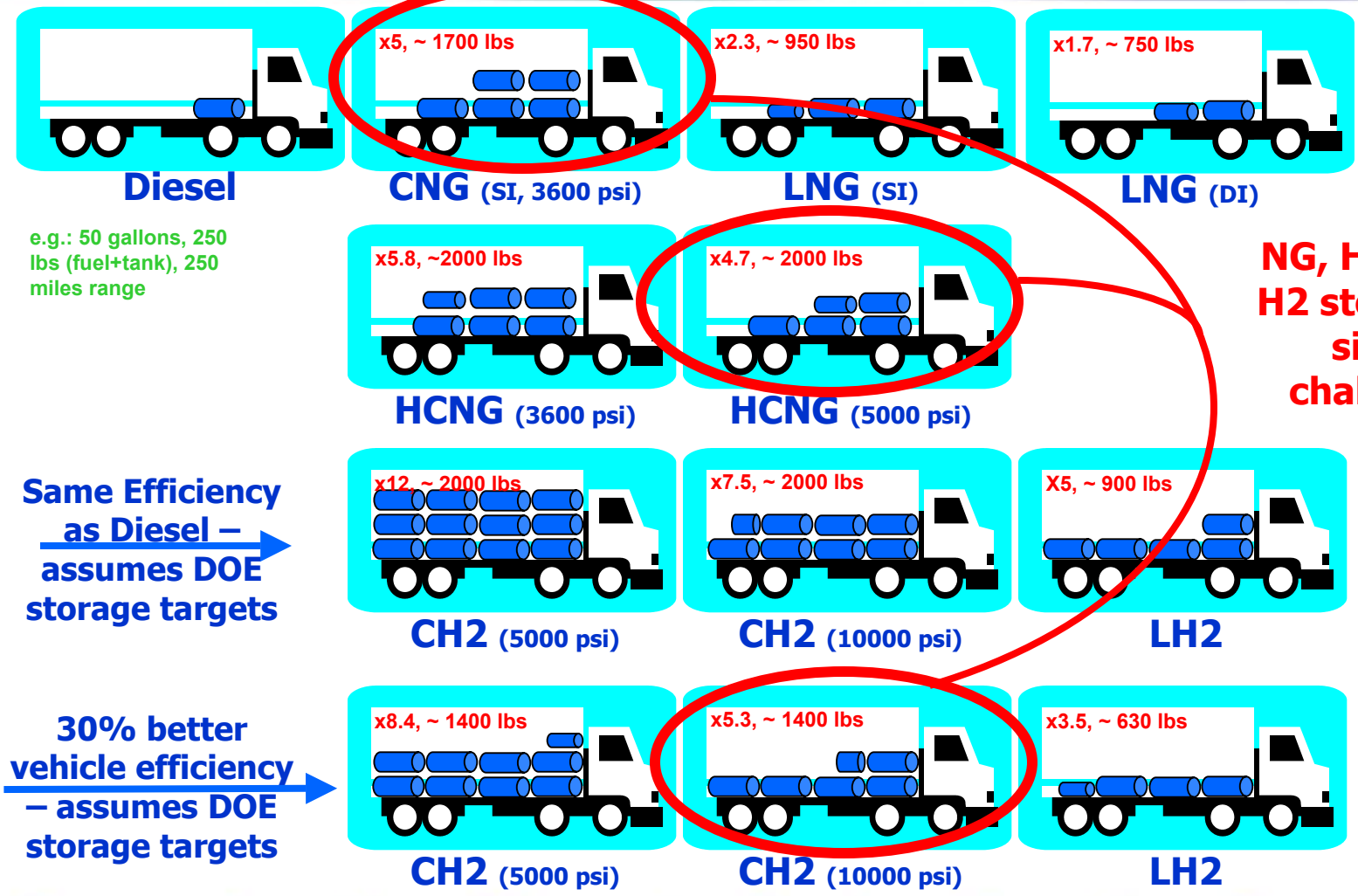
- Air pollution, climate change, diminishing reserve of petroleum fuels, large expected increase in world energy usage are forcing us to think in a new way about hydrogen
- There are clear challenges with hydrogen as a transportation fuel, but there are also enticing promises: dramatically reduced emissions of both GHG and atmospheric pollutants, as well as the opportunity to have a broadly used fuel produced from a variety of energy sources.
- We think the time is right to build on our gaseous fuels technologies and expertise to develop key enabling concepts for heavy-duty engines burning hydrogen

Heavy-Duty Vehicles and H_2

We have learned that heavy-duty commercial vehicles are good candidates for gaseous fuels utilization:

- Opportunity for central refueling (fleets)
- More controlled operations (range, maintenance, operation data logging)
- Better flexibility in creating space for the storage vessels
- Overall fleet has large and growing fuel consumption

H_2 vs NG Storage



Hydrogen Blended Natural Gas Fuel (HCNG)

A SunLine Transit Agency "SunBus" powered by hythane.

This NG bus was converted to run using HCNG during the Vancouver H2 conference

HCNG Benefits

- Enables introduction of H_2 fuel in technology with near-term commercial potential
- Enables increased load for potential or projected hydrogen stations
- Enables to gather experience with H_2 as a transportation fuel without the need for very expensive experimental vehicles
- Provides emissions benefits
  - SI lean burn engines can be calibrated for 50% lower NOx with only 20%$_{vol}$

HCNG Benefits

- Allows hydrogen fuel and equipment suppliers to develop volume and reduce costs
- Can build upon existing investment in natural gas infrastructure
- Challenges:
  - Energy Density (e.g. for 20%$_{vol}$, range is reduced by 10-15%)
  - Fuel Cost

SunLine Project

- Supported by NREL, SCAQMD, SunLine Transit
- Engine re-calibrated for 20%$_{vol}$ H_2, resulted in 50% NOx reduction over AVL 8-mode cycle without fuel economy or performance trade-off
- Needed to change mass flow sensor
- Engine shipped to SunLine, vehicles entered monitored service in early July.

AVL 8-Mode Composite for a 20%vol Hydrogen – NG blend on a CWI B Gas Plus Engine

Figure 2

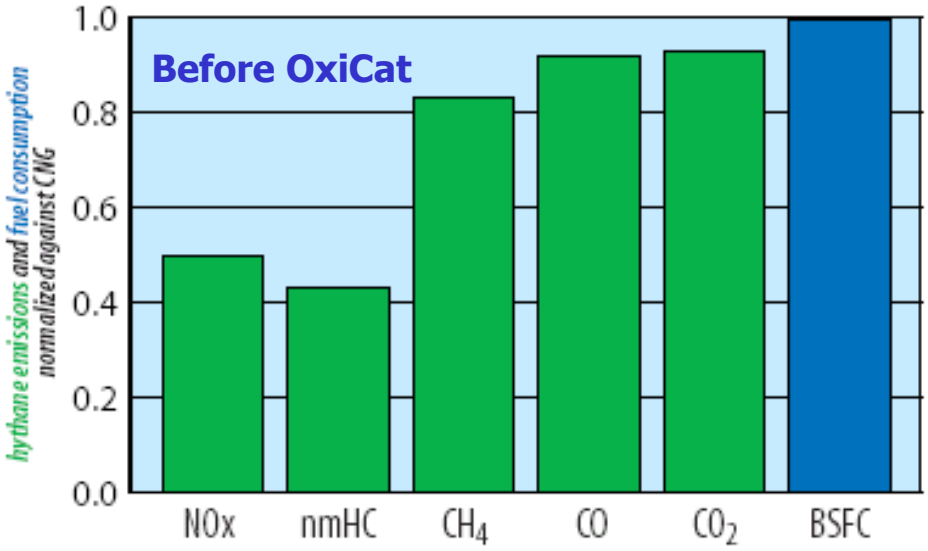
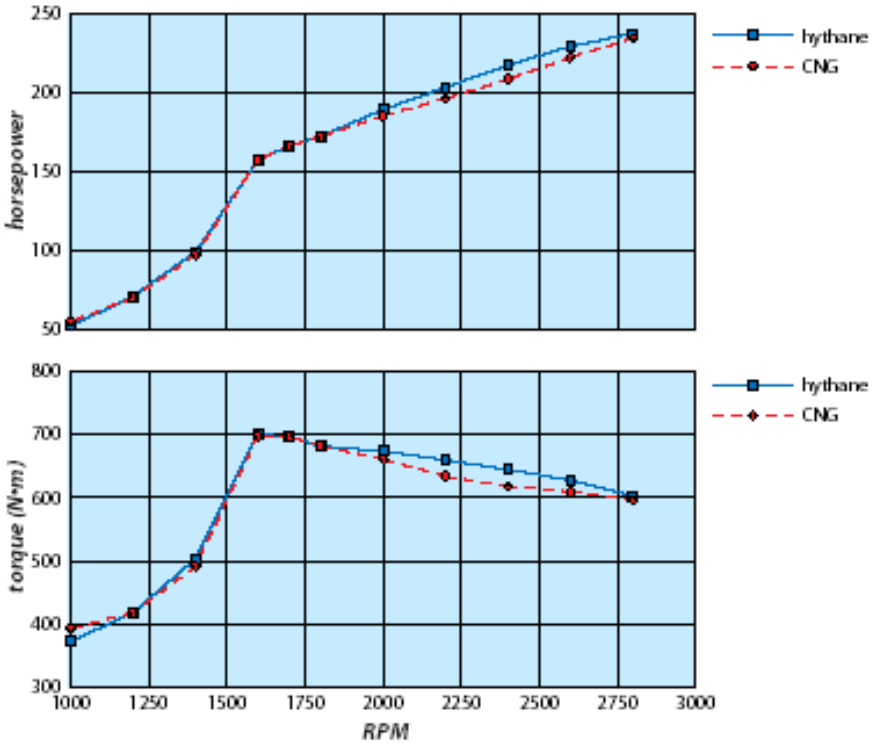


Figure 1



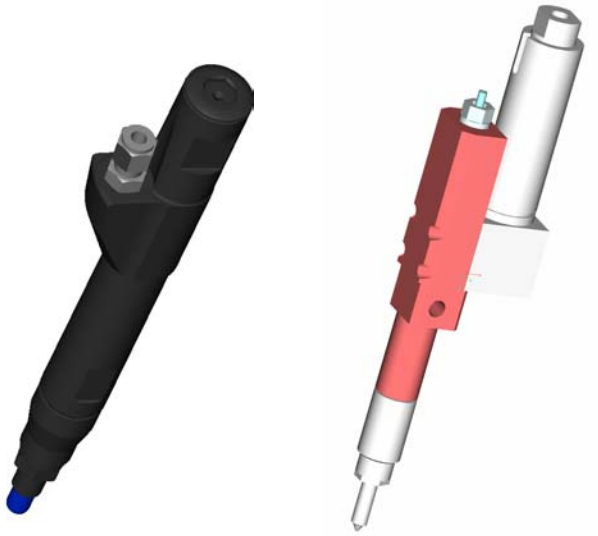
- NOx, nmHC reduced by 50%
- CO_2 reduced by 7%
- Energy consumption unchanged

HCNG Prospects

- We are evaluating HCNG's market potential
  - Need input from government agencies to determine interest
- CWI SI engines are ideal platforms for HCNG product development
- Although we have made some progress, a full product development is needed
  - e.g. calibrate the engine for the full range of environmental conditions, fuel composition, certify the product for emissions, establish the long term reliability and durability of components
- Need continued R&D efforts
  - e.g. higher H2 content, variable mixture capability, high efficiency calibration

Pure H2 Engines

HCI H2 125 kW Cummins/Onan Prototype Power Generation Unit



2 direct actuations H2 injector prototypes developed at Westport

Pure H2 engines – technologies from NG

- Key engine technologies have been developed for NG that are good basis for H2
  - Controlled, diluted-charge combustion: H2 can burn very diluted
  - Cooled EGR for ultra-low NOx
  - Robust spark ignition for HD applications
  - Direct injection: can mitigate pre-ignition, backfiring, allows CR increase and high BMEP
  - Combustion Diagnostic

Pure H2 Engines - Challenges

- Vehicle and engine efficiency improvements are key to hydrogen utilization in transportation:
  - To mitigate energy density of storage and range
  - To mitigate fuel cost
  - To mitigate energy intensity and GHG

Pure H2 Engines - Opportunities

- NG-derived engine technologies could be coupled with engine and vehicle efficiency improvement technologies:
  - For example, many categories of HD vehicles could benefit from hybridization and the utilization of Auxiliary Power Units (APU)

Summary

- We have a track record of technology development and commercial product introduction for gaseous fuels in commercial HD engines
- We have developed key engine technologies for natural gas that are building blocks for Hydrogen
- We are interested in understanding and developing hydrogen technologies in partnership with DOE
- We believe that HCNG represents a unique near-term opportunity to introduce hydrogen in the transportation fuel mix

Thank you

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